

Visualization and Criticality of Magnetotail Field Topology in a Three-dimensional Particle Simulation

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We present the temporal evolution of magnetic field topology in the magnetotail with a southward IMF in order to identify the magnetic reconnection. The magnetic field topology is uniquely determined by the eigenvalues of the critical points, if they are not degenerated. This is because the critical points, their number, and the rules between them characterize the whole magnetic field pattern. At the critical points, the magnetics become zero. The magnetic vector field curves and surfaces are both integrated out along the principal directions of certain classes of critical points including the Earth's dipole magnetic field. The skeleton that includes the critical points, characteristic curves, and surfaces provides the three-dimensional topological structure of the reconnection. The change of the skeleton, i.e. the change of the topology, has revealed the occurrence of magnetic reconnection. Namely, three-dimensional “X-points” or the more-than-two critical points that are saddle and connected each other are unstable and can move, vanish, and generated.

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1. Introduction

Three-dimensional magnetic field topology in magnetosphere represents a domain of space plasma physics of great interest that is, as yet, beyond the reach of definitive theoretical analysis or numerical computations. At present, our understanding of three-dimensional magnetic field rests principally on observations drawn from experimental satellite data or some global simulations of the Earth magnetosphere.

On the other hand, when computer graphics were introduced as a field of study, the visualization techniques based on it were closely resemble to the “pictures” that were already in use in the field. The researchers who had examined thousands of them, have recognized that images that actually contain more information are useful than new presentations. However, direct visualization methods in which thousands of points, vectors or curves are displayed are inadequate to visualize many complex data sets. Furthermore, manually choosing a smaller set of elements for direct display is usually both time-consuming and misleading.

Our research was motivated by the importance of topology in order to understand the dynamics of magnetic field in the magnetotail. We have noticed that it is difficult to understand the topology in the complex magnetic fields with the existing tools. In this paper,

we present some methods that automate the analysis and display magnetic field topology in the near Earth, especially in the magnetotail where the magnetic reconnection occurs. First, we describe the basis of critical point analysis and classifications, and the three-dimensional algorithm of our visualizations. Second, we visualize the three-dimensional magnetic field topology in the magnetotail in order to reveal the global change of topology. The visualizations are based on the numerical data sets obtained by the three-dimensional electromagnetic particle simulation [Nishikawa, 1997, 1998a].

Topology provides useful information on the entire magnetic field structure with the simplified magnetic fields displayed by the critical points and surfaces based on the eigenvalues, which will be discussed later. Critical points of the field can be categorized mathematically. Thus the types of critical points, their number, and the rules governing the relations among them can characterize the magnetic field pattern. Magnetic reconnections in this view has been defined by the change of this structure following the rules governing the relations among them. However, this view of reconnections is not universally accepted, and requires further investigation.

2. Critical Points

Critical points or magnetic nulls are the points where the magnitude of magnetic field vector vanishes. These points may be characterized by the behavior of nearby magnetic field curves or surfaces. The set of curves or surfaces which end on the critical points is of special interest because it defines the behavior of the magnetic field in the neighborhood of the critical point. If all the eigenvalues of critical points in the region where we consider are hyperbolic, then the magnetic vector field

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